# New Perspectives: A Few Innovative Ways to Analyze MOVES Data in Support of Regional Modeling in Mobile Source Emissions

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# Presentation Outline

- Background
- MOVES Emission Processes
- Data Analyses on Lookup Tables
- Effect of Relative Humidity
- Effect of Reid Vapor Pressure
- Effect of Vehicle Fleet Age
- Algorithm Separating Emission Processes
- Temporal Profiles
- Summary and Conclusion

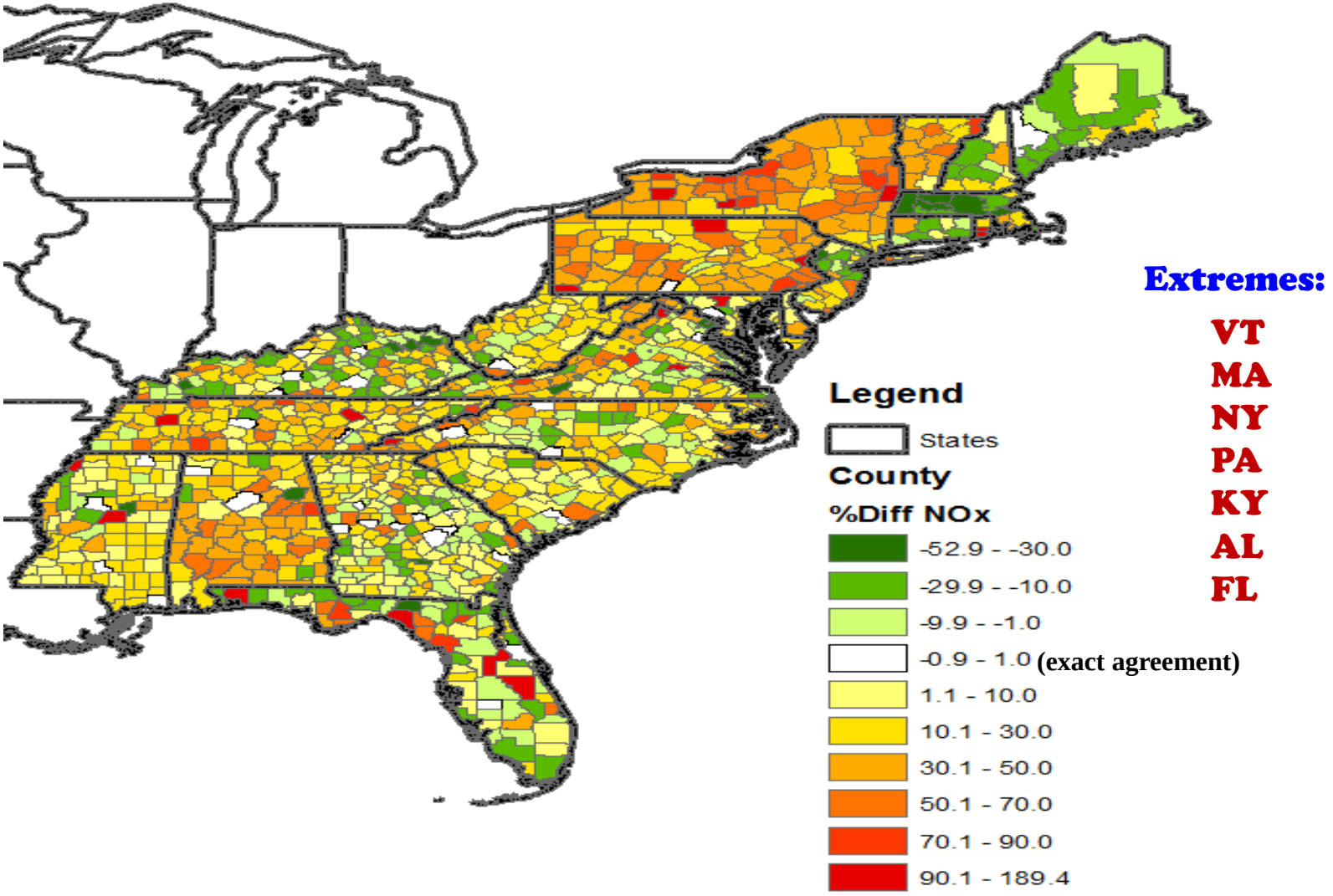
# Background

## Operation modes for MOVES and SMOKE-MOVES:

| Mode | (1) Inventory Mode | (2) Emission Rate Mode | (3) Lookup Table Mode |
|---|---|---|---|
| Model | MOVES | MOVES | MOVES, SMOKE-MOVES |
| Primary Usage | Emission inventory development | Sensitivity runs | Regional emission modeling |
| Strength | Local data, No post-processing required | Detailed emission processes | Detailed meteorology, Large scale modeling |
| Weakness | Generalized meteorology | Complex outputs in emission rates | Representative county, Difficult to operate |
| Resolution | County, Month | County, Month | Representative county, Fuel month |
| Challenges | SCCs | SCCs | SCCs, Relative humidity |

# 2007 RPOs versus 2007 EPA for NOx (lookup table mode)

**(2007LKP – 2007EPA) *100 / 2007EPA**




**Extremes:**

**VT**
**MA**
**NY**
**PA**
**KY**
**AL**
**FL**

**Very large variability in NOx is seen between RPOs and EPA estimates. Differences range from -50% to +200%.**

# Current Status

- MOVES by itself is not suitable for regional scale modeling
- SCCs implemented in MOVES are severely flawed
- Crude approaches for representative county and (two) fuel month in SMOKE-MOVES greatly minimize (or reduce) spatial and temporal resolutions
- Effect of relative humidity cannot be simulated in SMOKE-MOVES
- SMOKE-MOVES is complicated, cumbersome, inconsistent, and confusing

**Complicated**: 3 models, MOVES, SMOKE-MOVES, SMOKE;
**Cumbersome**: Linux/Windows platform switches;
**Inconsistent**: implementation b/w MOVES and SMOKE-MOVES;
**Confusing**: documentation inadequate

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# MOVES Emission Processes

| Process ID | Abbreviation | Process Name |
|---|---|---|
| 1 | EXR | Running Exhaust |
| 2 | EXS | Start Exhaust |
| 9 | BRK | Brakewear |
| 10 | TIR | Tirewear |
| 11 | EPM | Evap Permeation |
| 12 | EFV | Evap Fuel Vapor Venting |
| 13 | EFL | Evap Fuel Leak |
| 15 | CXR | Crankcase Running Exhaust |
| 16 | CXS | Crankcase Start Exhaust |
| 17 | CEI | Crankcase Extended Idle Exhaust |
| 18 | RFV | Refueling Displacement Vapor Loss |
| 19 | RFS | Refueling Spillage Loss |
| 90 | EXT | Extended Idle Exhaust |
| 99 | | Well-to-Pump |

**EXR/CXR:** running exhaust
**EXS/CXS:** start exhaust
**EXT/CEI:** extended idling

**EPM, EFV, EFL, EFV, EFS:**
VOCs related processes

**BRK, TIR:**
PM related processes

# Emission Processes by Sector

| RPD | | RPV | | RPP | |
|---|---|---|---|---|---|
| Rate-Per-Distance | | Rate-Per-Vehicle | | Rate-Per-Profile | |
| **MOVES** | **SMOKE** | **MOVES** | **SMOKE** | **MOVES** | **SMOKE** |
| EXR | | EXS | | EFV | EVP |
| CXR | EXH | CXS | EXH | | |
| EPM | EPM | EPM | EPM | | |
| EFV | | EFL | EVP | | |
| EFL | EVP | EXT | | | |
| BRK | BRK | CEI | EXT | | |
| TIR | TIR | | | | |

RPD: vehicles in motion (running emissions)
RPV: vehicles motionless (cold start, extended idling)
RPP: parked vehicles (fuel vapor venting, VOCs only)

RPV (rate-per-vehicle) should not to be confused with RVP (Reid Vapor Pressure)

# Additive Mechanism

- **By pollutants in MOVES :**

RPD = (EXR + CXR) +
EPM_VOC+ EFL_VOC + EFV_VOC +
BRK_PM25 + TIR_PM25;
RPV = (EXS + CXS) + (EXT + CEI) +
EPM_VOC + EFL_VOC;
RPP = EFV_VOC

RPD: vehicle in motion
RPV: vehicle motionless
RPP: parked vehicles

- **By pollutants in SMOKE-MOVES:**

RPD = EXH +
EPM_VOC+ EVP_VOC +
BRK_PM25 + TIR_PM25;
RPV = EXH+ EXT +
EPM_VOC + EVP_VOC +
RPP = EFV_VOC

function of speed

Total Hourly Emissions =
RPD (speed) * VMT * temporal factor +
RPV (hr)* VPOP +
RPP (hr) * VPOP

function of hour

Processes which behave differently should not be aggregated in SMOKE-MOVES

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  - Systematic sensitivity runs
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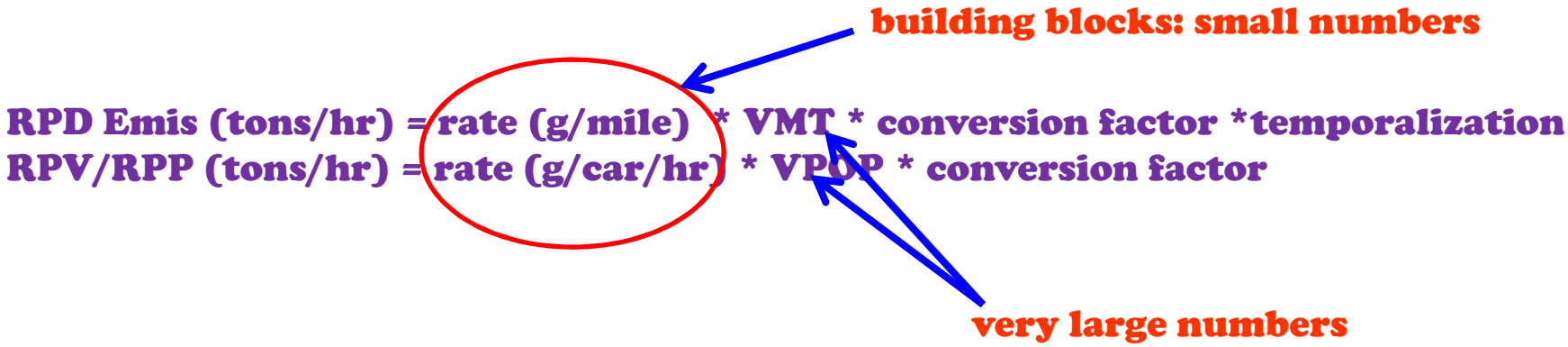
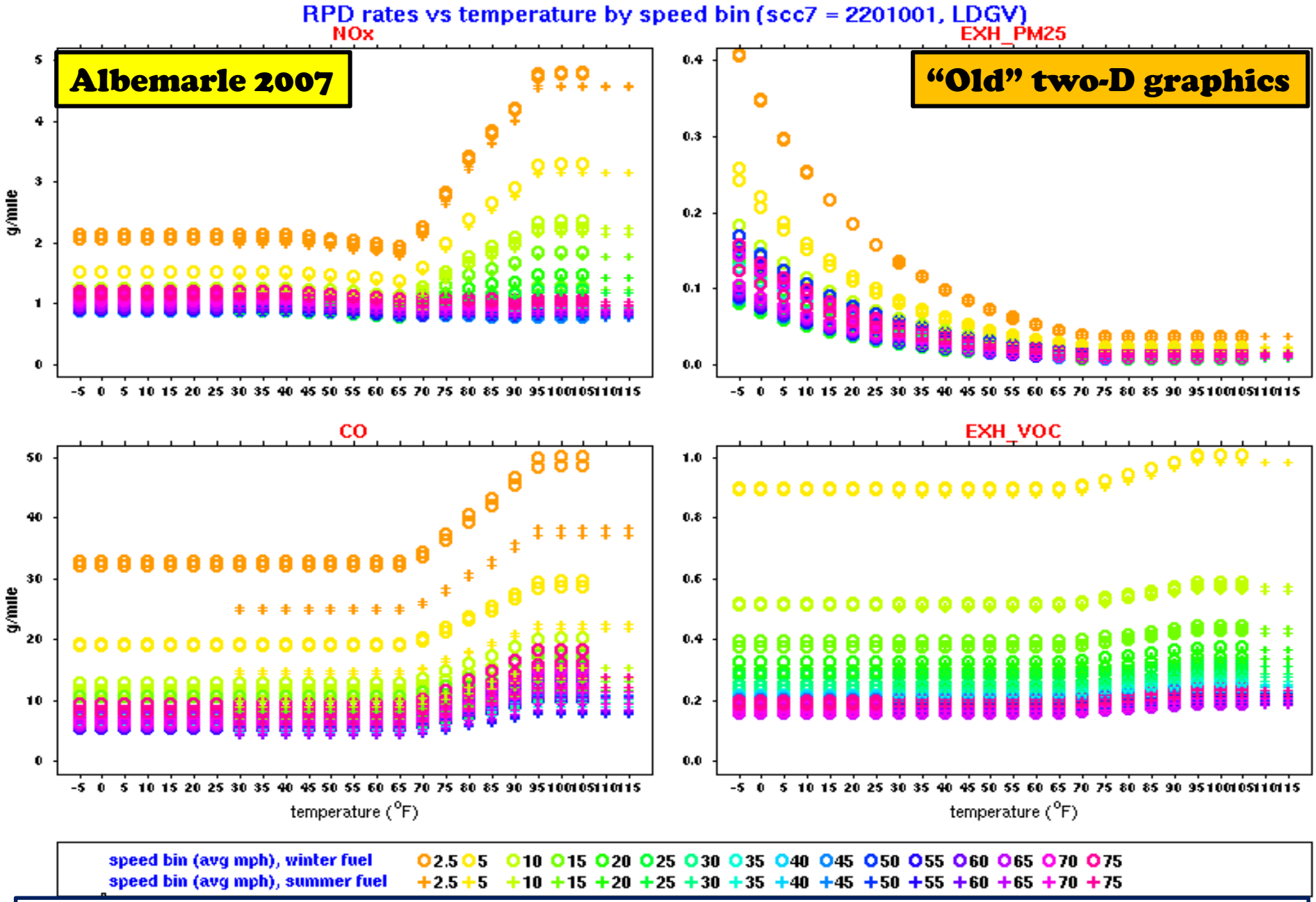
# SMOKE-MOVES Lookup Tables

- **Lookup tables contain millions of data records of emission rates for a variety of modeling conditions:**

  **example: 0.8 g/mile of NOx for LDGV travels at 50 mph on urban freeway (SCC = 2201001250) at ambient temperature of 60F**

- **Emission rates vary widely if conditions (county, fuel month, SCCs, speed, temperature) change**
- **Rates are small numbers (in unit activity of g/mile or g/car/hr). They are the building blocks for emissions and must be accurately generated prior to combination with activity. The accuracy hinges on MOVES runs using local, state-supplied inputs of surrogated counties**





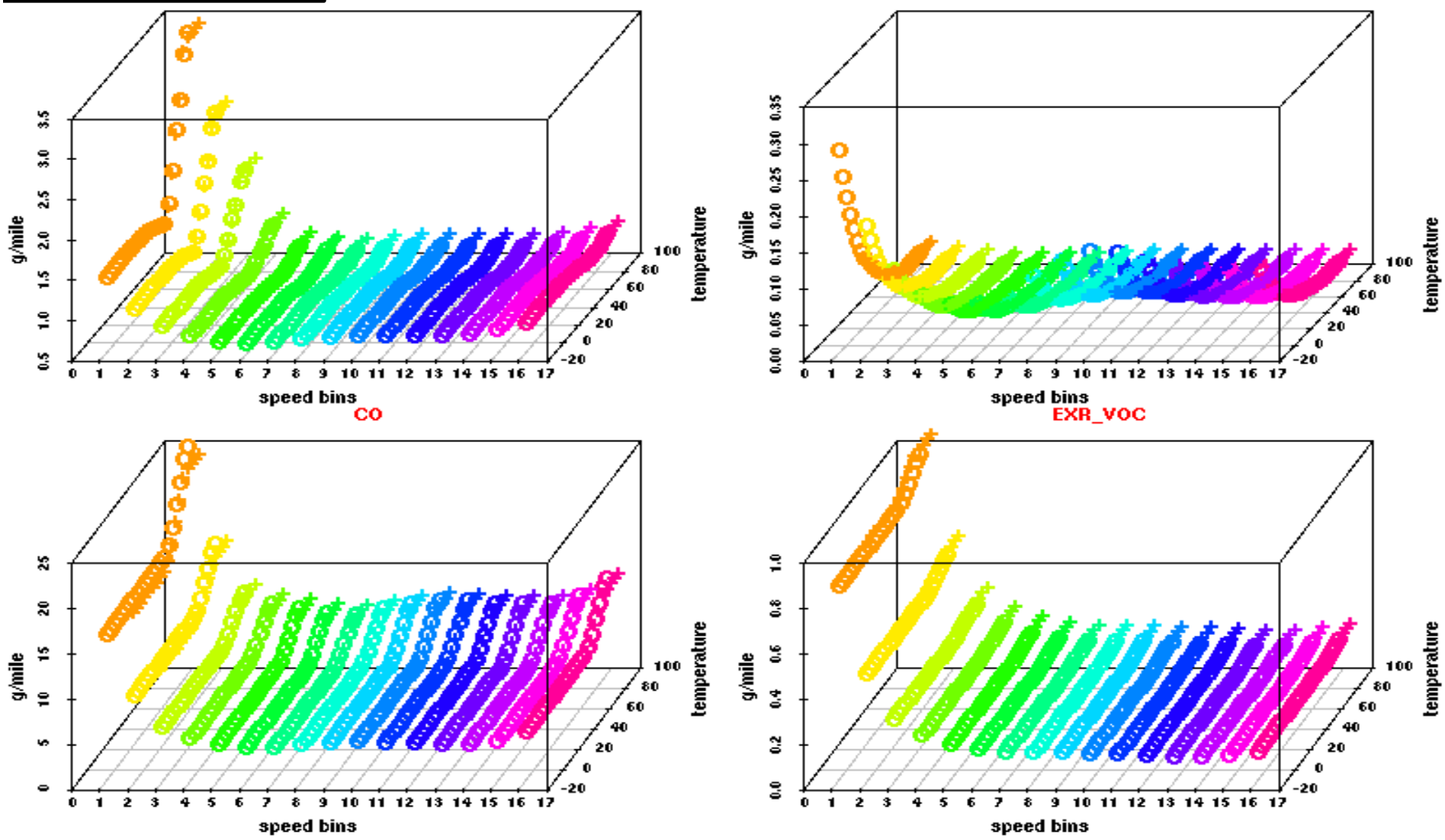

-- LDGV releases more NOx and CO at higher temperatures, but emits more PM2.5 at lower temperatures.
-- The lower the speed an LDGV travels, the higher the emissions for all pollutants.
-- Winter and summer fuels affect CO only. Winter fuel has higher CO emission rates than summer fuel.

# Rate-Per-Distance (RPD) by Pollutants – Running Exhaust (EXR)

**Albemarle 2011**

EXR (running exhaust) rates for scc = 2201001110

**LDGV, Rural Interstate**

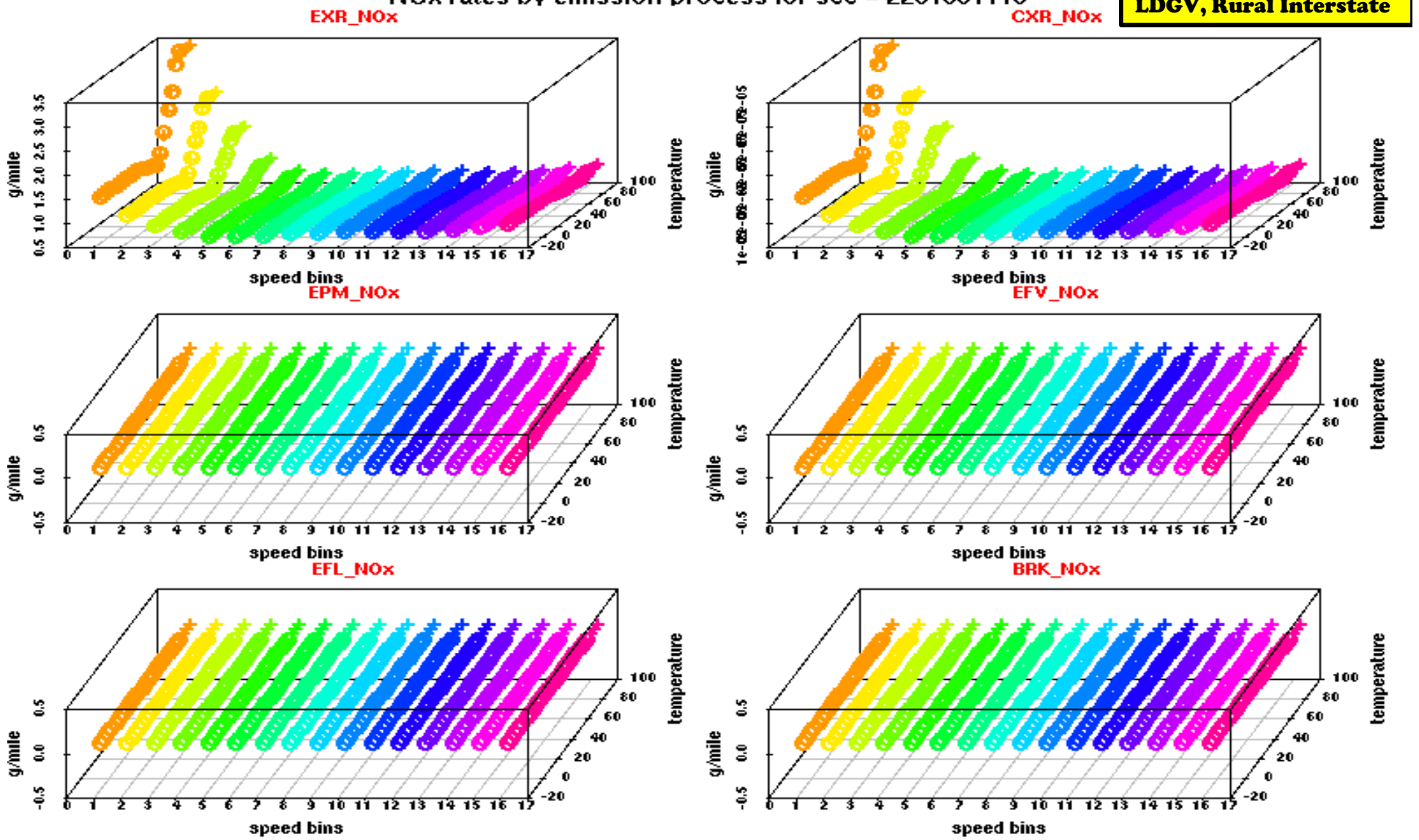



-- The lower the speed an LDGV travels, the higher the emissions for all pollutants.

-- LDGV releases more NOx and CO at higher temperatures, but emits more PM2.5 at lower temperatures.

# Rate-Per-Distance (RPD) by Emission Process – NOx

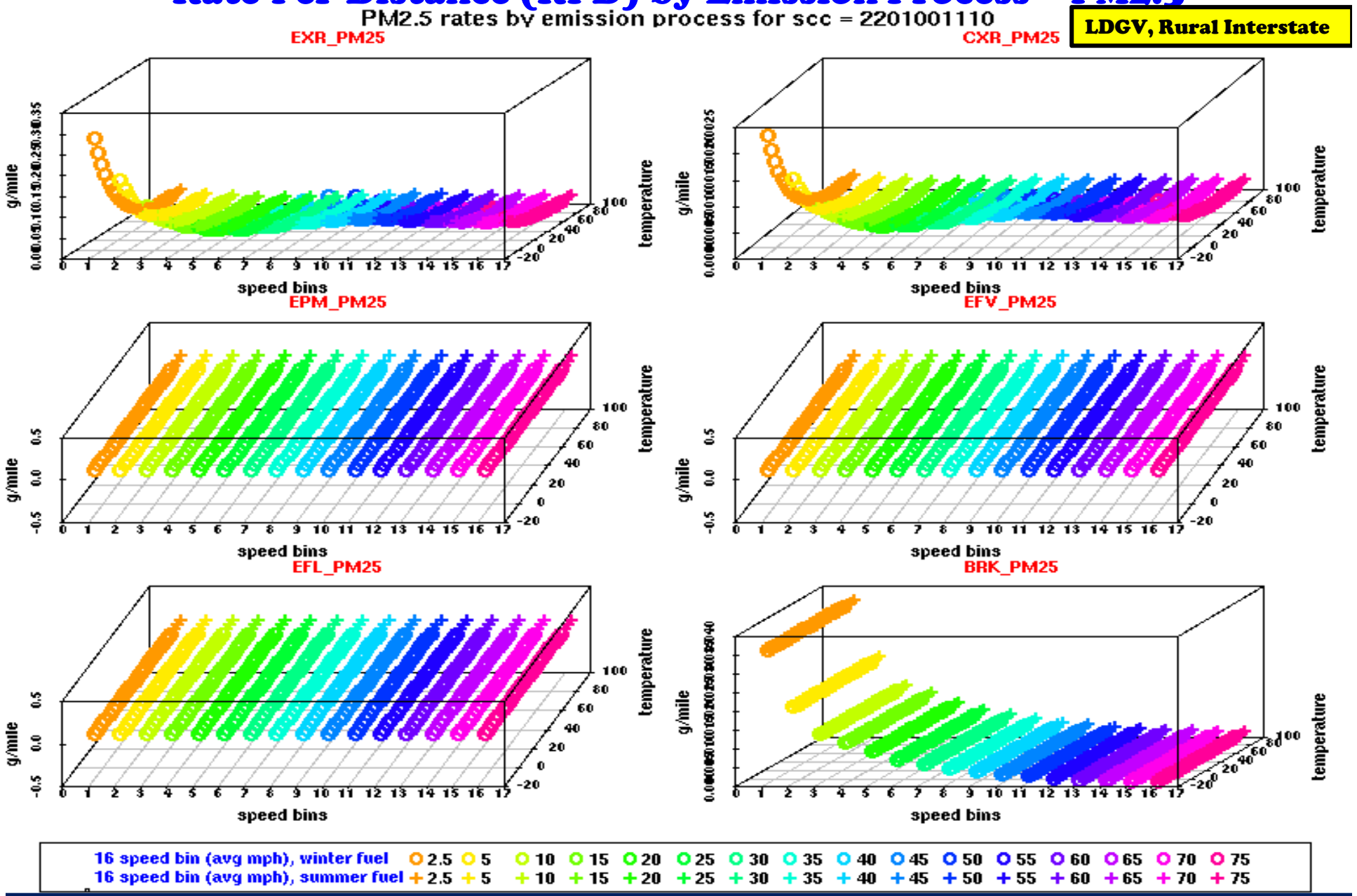
**LDGV, Rural Interstate**




-- In RPD sector, only running exhaust (EXR) and crankcase running exhaust (CXR) release NOx.

-- NOx are not present in brakewear (BRK) or VOC related processes (EPM, EFV, EFL).

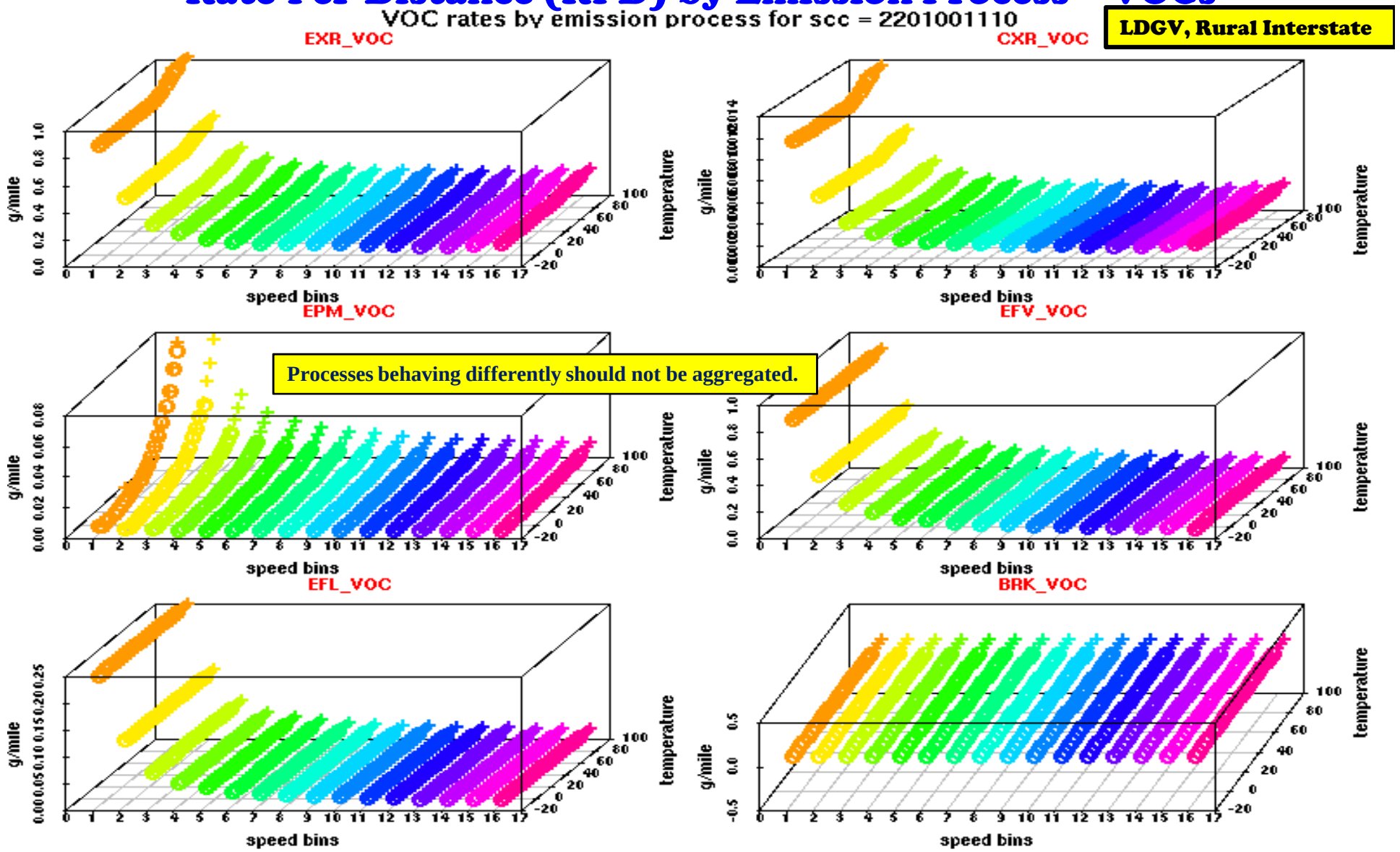
# Rate-Per-Distance (RPD) by Emission Process – PM2.5




-- In RPD sector, running exhaust (EXR), crankcase running exhaust (CXR), brakewear (BRK), and tirewear (TIR) emit PM2.5

-- PM2.5 are not present in VOC related processes (EPM, EFV, EFL). PM2.5 in brakewear (BRK) have no temperature dependence.

# Rate-Per-Distance (RPD) by Emission Process – VOCs

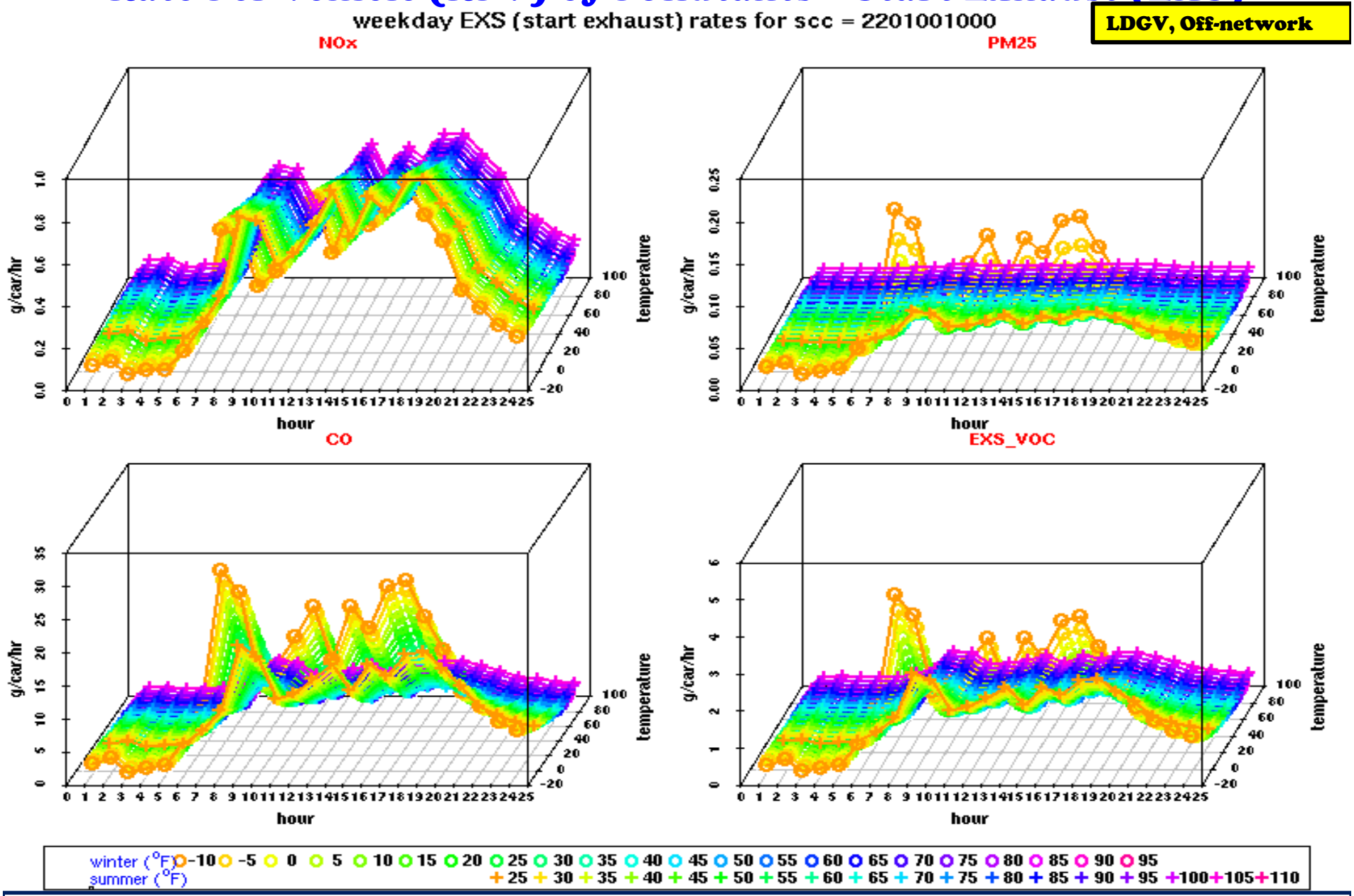



-- All emission processes release VOCs with the exception of brakewear (BRK).

-- VOCs in evaporative permeation (EPM) have much greater temperature dependence but less speed dependence than other processes.

# Rate-Per-Vehicle (RPV) by Pollutants – Start Exhaust (EXS)

**LDGV, Off-network**

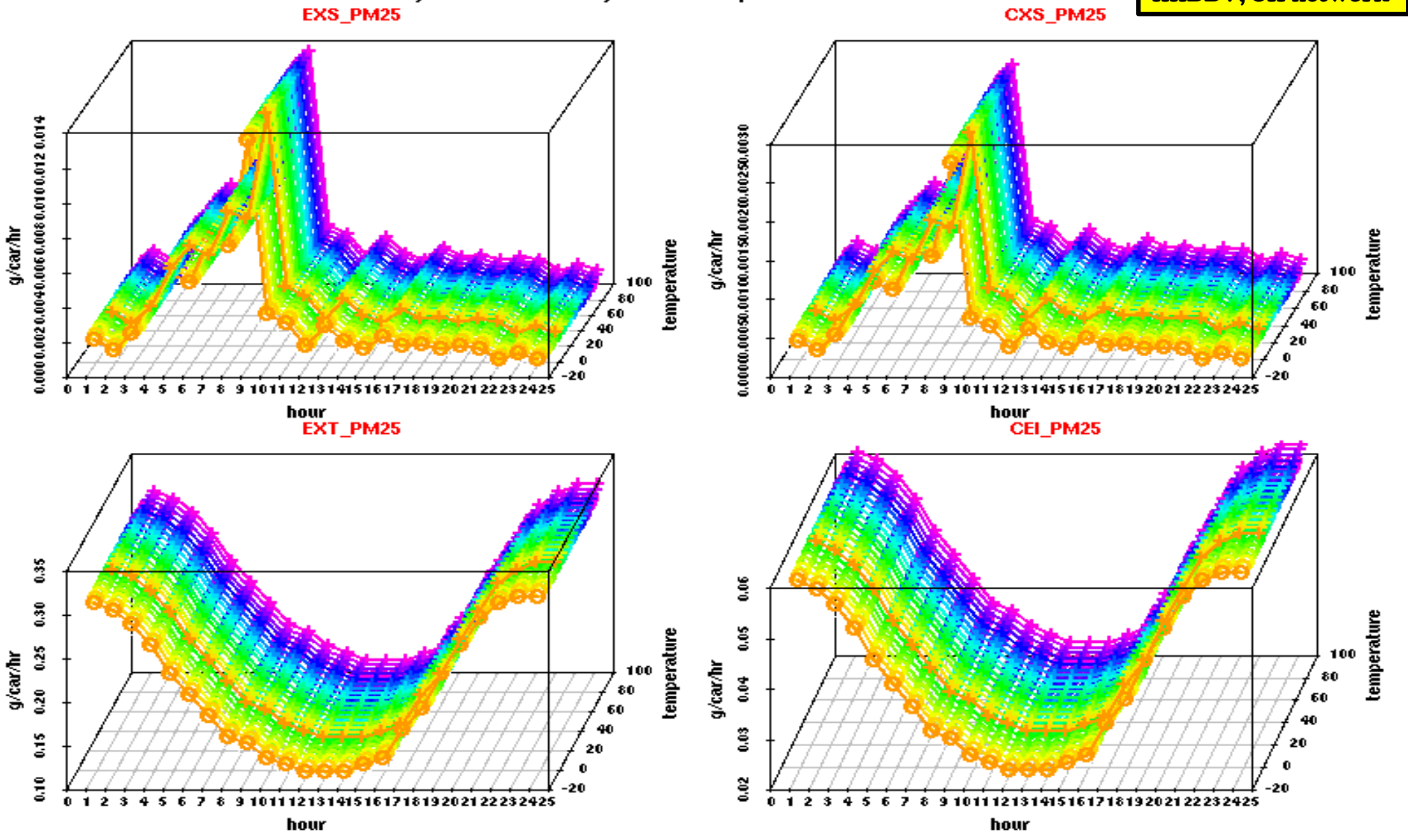



-- For LDGV, MOVES has pre-set four emission peak hours at 8am, 1pm, 3pm, and 6pm. Rates are lower at off-peak hours.

-- The four peak hours are pre-determined internally in MOVES. Unless modifying default database, the peak hours cannot be changed.

# Rate-Per-Vehicle (RPV) by Process – PM2.5

**HHDDV, Off-network**




-- For HHDDV, MOVES has also pre-set peak hours. Engine start (EXS/CXS) have different profiles from extended idling (EXT/CEI).

-- Emission rates for HHDDV are higher at off-peak night-time and wee hours when drivers turn on the engines and sleep in the trailers.

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  Assumed constant in SMOKE-MOVES
- Effect of Reid Vapor Pressure
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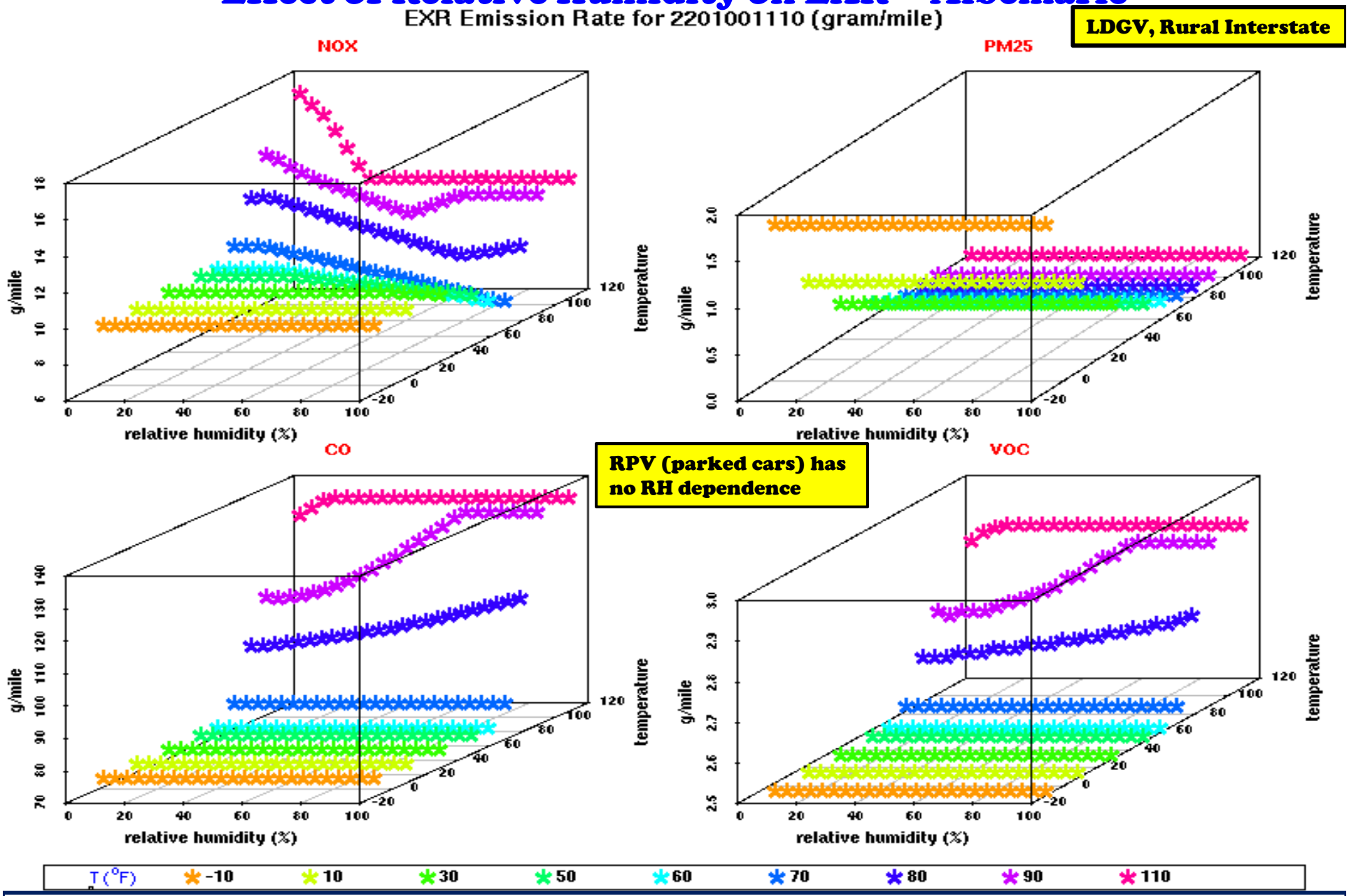
# Effect of Relative Humidity on EXR – Albemarle

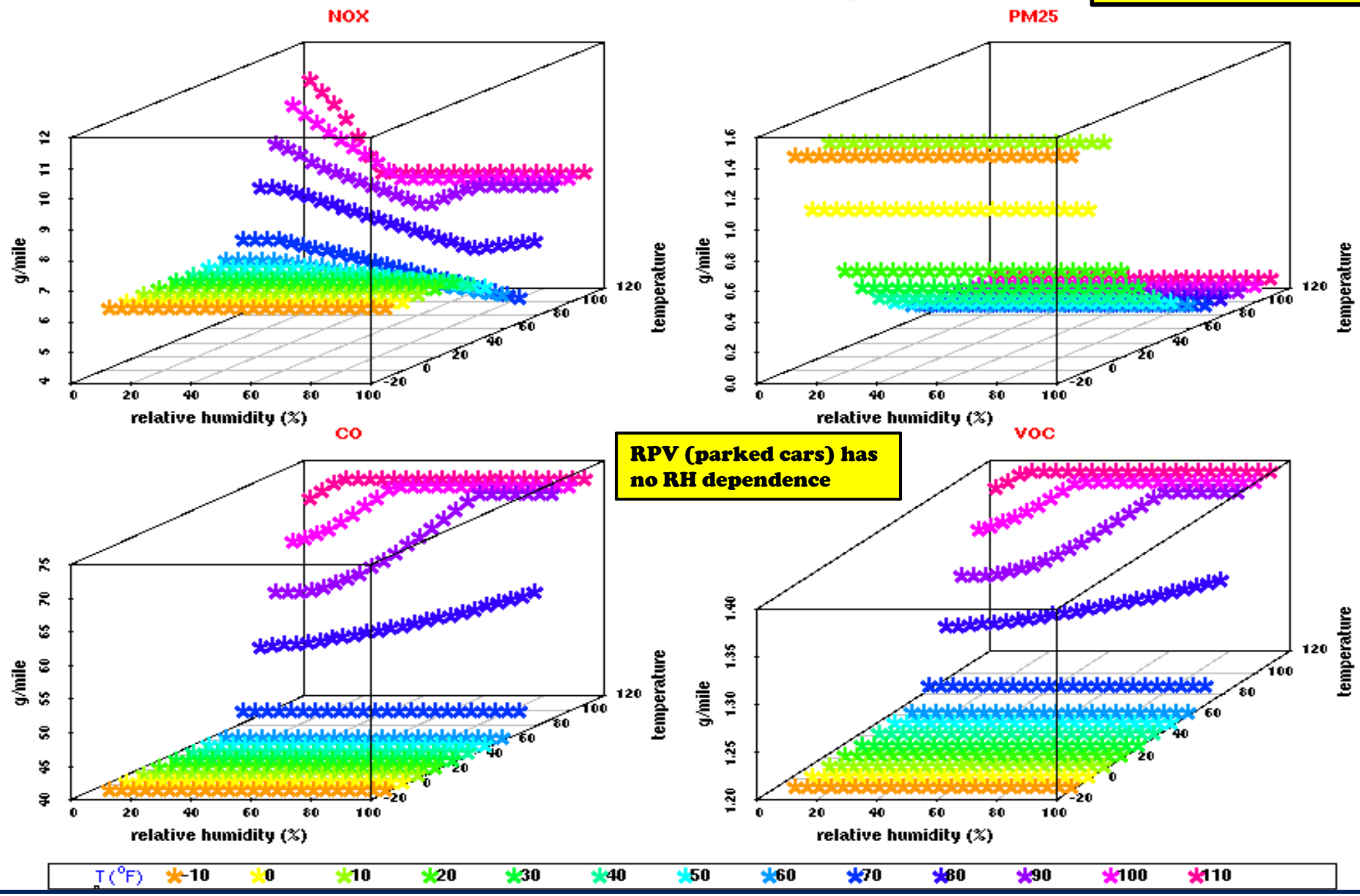



-- Relative humidity affects emission rates when temperatures are above 60F. The effect levels off as temperature increases.

-- All criteria pollutants except PM2.5 are affected by relative humidity. NOx are high at low RHs.

# Effect of Relative Humidity on EXR – Fairfax

**LDGV, Rural Interstate**




-- Fairfax run show similar trends to those of Albemarle. Does relative humidity refer to ambient or air-conditioned condition?

-- Relative humidity exerts similar effect on emission rates regardless of county (and likely regardless of base year or model version as well).

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- Effect of Reid Vapor Pressure

  Two fuel-month practice in SMOKE-MOVES
- Effect of Vehicle Fleet Age
- Algorithm Separating Emission Processes
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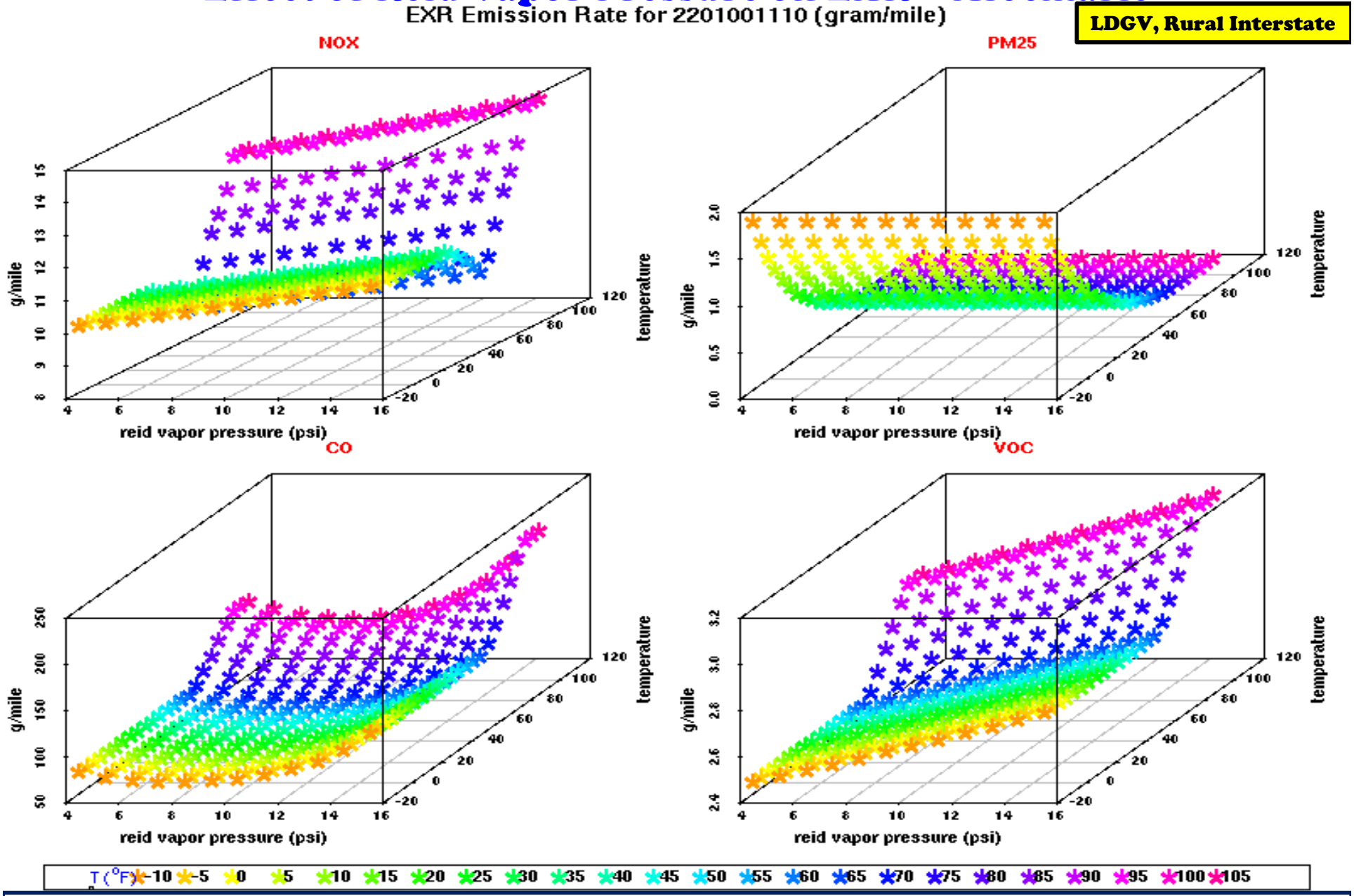
# Effect of Reid Vapor Pressure on EXR – Albemarle

**LDGV, Rural Interstate**



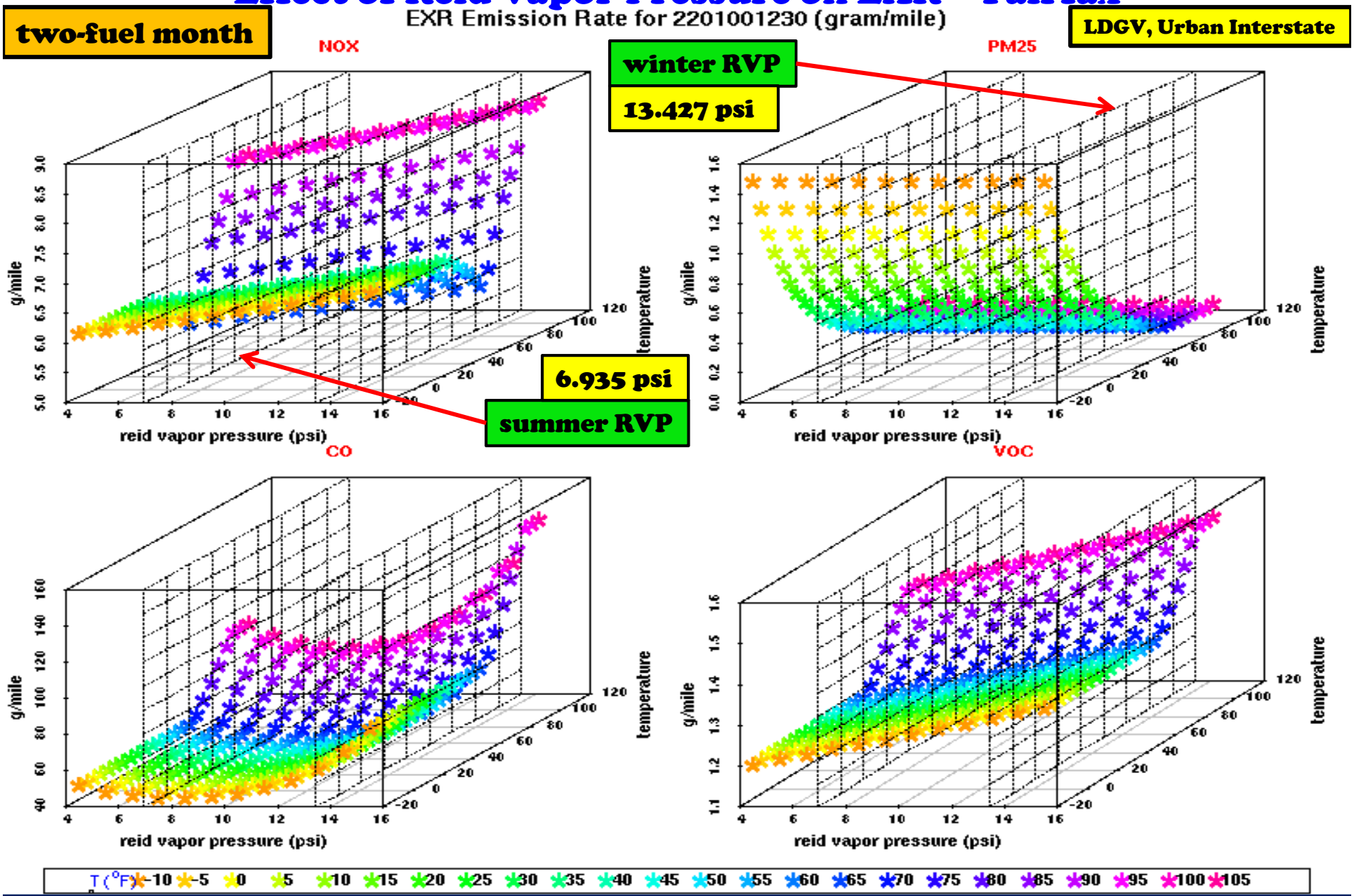

-- Fuels with higher Reid Vapor Pressure release higher emissions. All criteria pollutants except PM2.5 are affected by RVP.

-- NOx rates are higher at higher temperature, whereas PM2.5 rates are higher at lower temperature. Consistent with what's shown in other slides.

# Effect of Reid Vapor Pressure on EXR – Fairfax

**two-fuel month**

**LDGV, Urban Interstate**




-- Fairfax run shows similar trends to Albemarle. Effect of Reid Vapor Pressure has significant implication for fuel month approach.

-- Effect of Reid Vapor Pressure are similar regardless of county (and likely regardless of base year or model version as well).

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- Effect of Vehicle Fleet Age --

  Important factor affecting emissions
- Algorithm Separating Emission Processes
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- Summary and Conclusion

# Fleet Age Sensitivity Setup

## Fairfax/Albemarle 2011

| Model Year | Control | Scenario1 | Scenario2 | Scenario3 |
|---|---|---|---|---|
| 20-31 years (1981-1990) | 0.03225 | -5% | -5% | +10% |
| 10-20 years (1991-2000) | 0.03225 | -5% | +10% | -5% |
| 0-10 years (2001-2011) | 0.03225 | +10% | -5% | -5% |

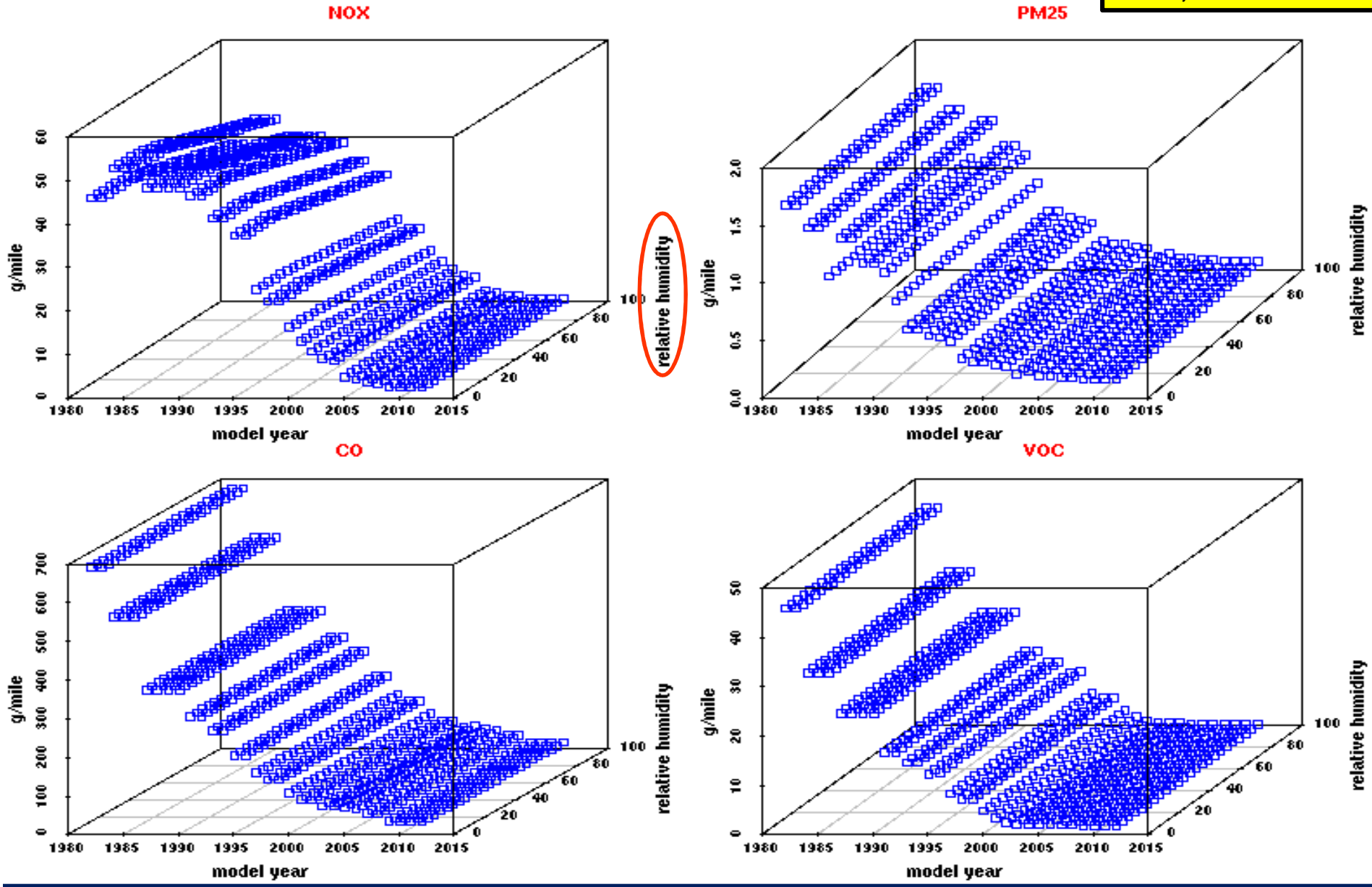
* County is assumed to have a hypothetical fleet of 1/31 (0.03225) for all vehicle types;
* Scenario1 increases newest fleet by 10% and decreases the older fleets by 5%;
* Scenario2 increases middle-aged fleet by 10% and decreases the other two fleets by 5%;
* Scenario3 increases the oldest fleet by 10% and decreases the newer fleets by 5%;
* Fractions for a particular vehicle type must sum up to 1.

**Addition dimension, vehicle model year, is involved in model input/output and post-processing**

# Effect of Fleet Age on EXR – Albemarle 2011 (control base case)

EXR Emission Rate for 2201001110 at T=60F (gram/mile)

**LDGV, Rural Interstate**



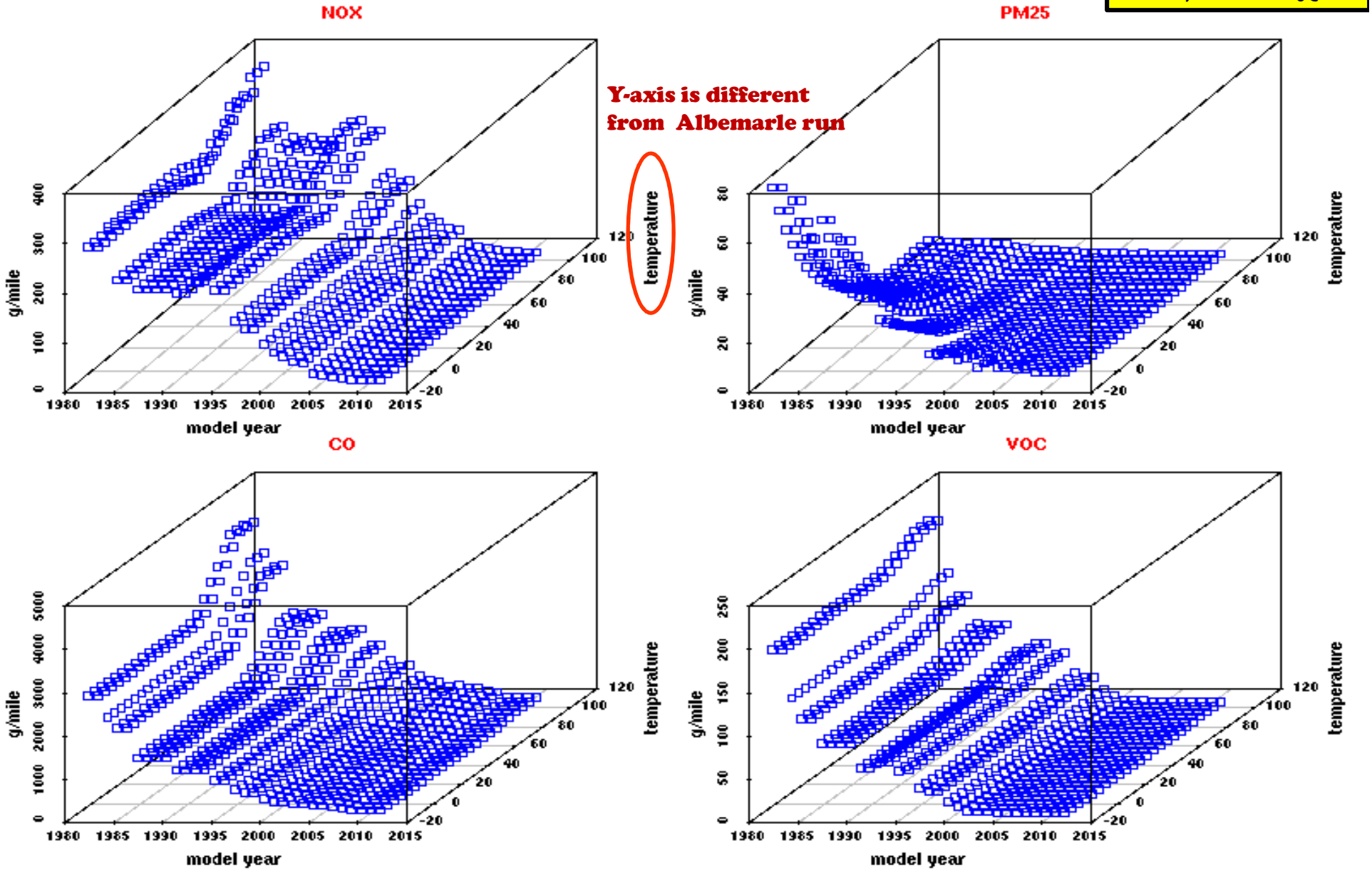

-- Age of LDGV fleet spans 31 years from model year 1981 to model year 2011.

-- Emission rates are higher for older vehicles (i.e., older cars are dirtier).

# Effect of Fleet Age on EXR – Fairfax 2011 (control base case)

EXR Emission Rate for 2201001 at RH=60% (gram/mile)

**LDGV, All road types**




**Y-axis is different from Albemarle run**

-- Age of LDGV fleet spans 31 years from model year 1981 to model year 2011.

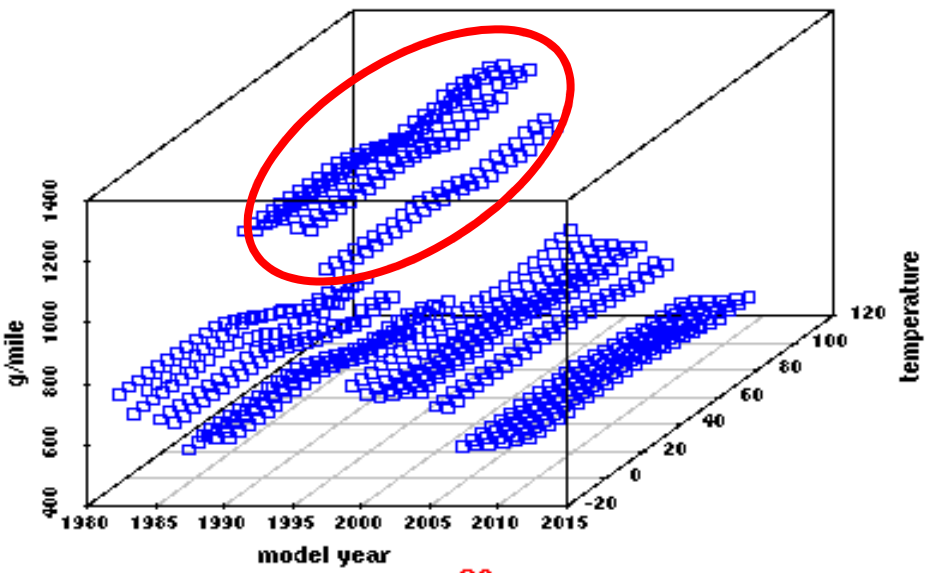
-- Emission rates are higher for older vehicles (i.e., older cars are dirtier.) Different counties (Fairfax vs Albemarle) show similar trends.

# Effect of Fleet Age on EXR – Fairfax 2011 (control base case)

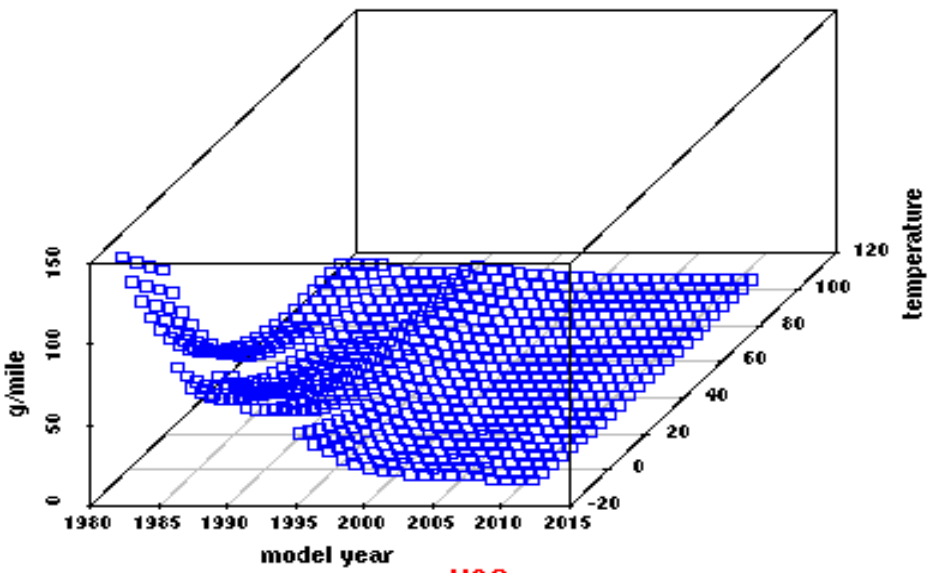
EXR Emission Rate for 2201070 at RH=60% (gram/mile)

**HDGV, All road types**

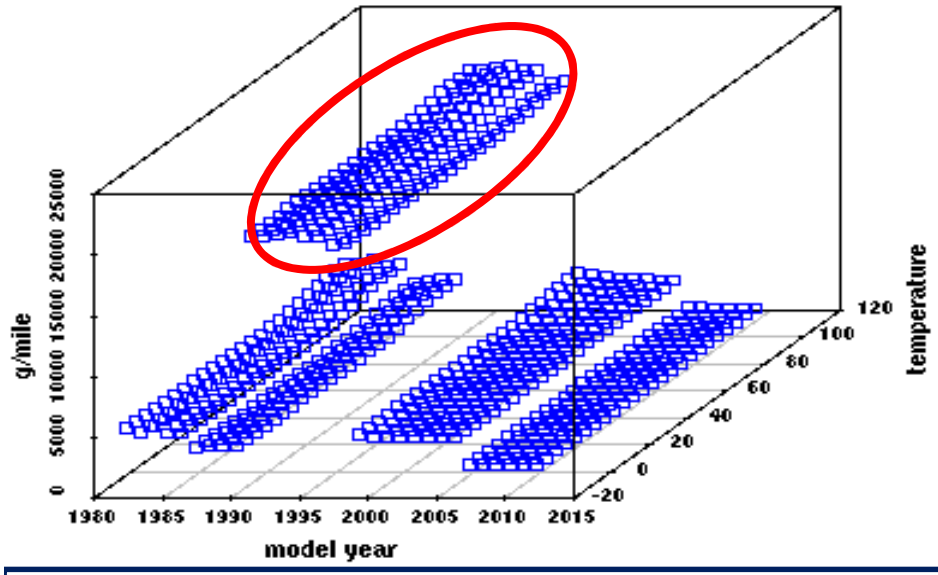
NOX



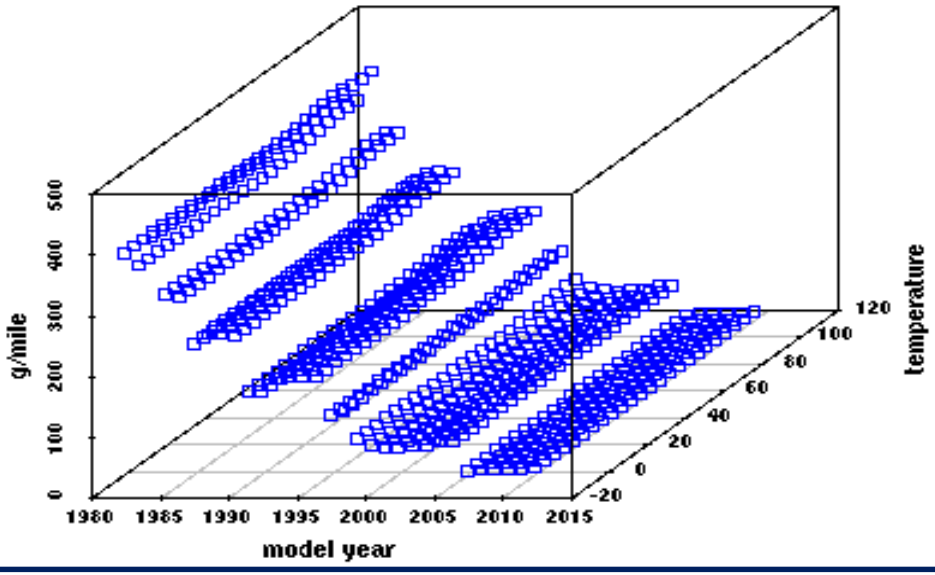

PM25




CO




VOC




-- HDGV in some model years get higher emission rates than other model years???

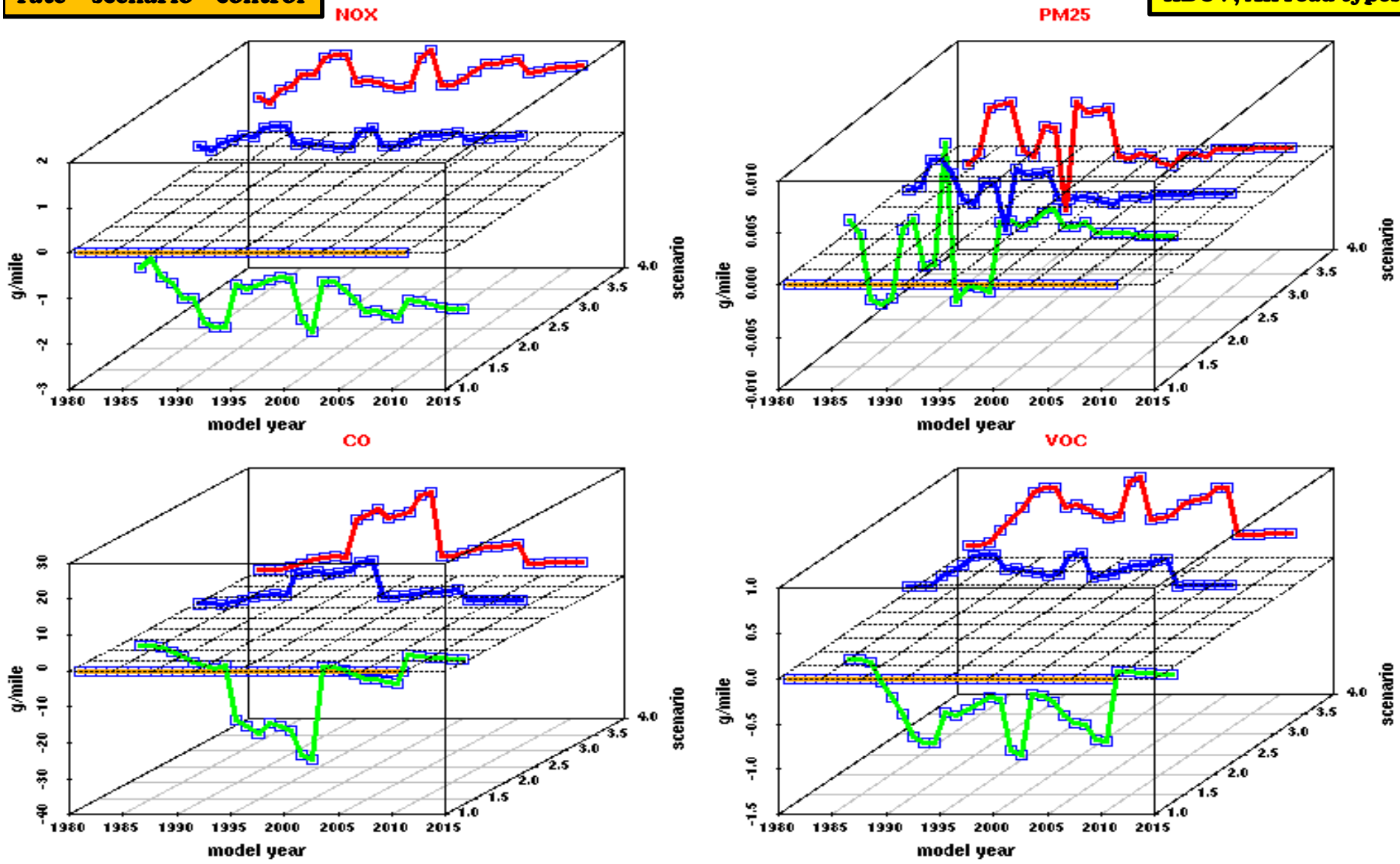
-- MOVES seems to have internally pre-determined emission rates according to model year for some vehicle types.

# Effect of Fleet Age on EXR – Fairfax 2011

**rate = scenario -- control**

Differences in EXR Emission Rate for 2201070 at T=70F, RH=60%

**HDGV, All road types**




-- Rates are shown as differences between scenario and control case. Control case subtracts itself to be zero for all model years.

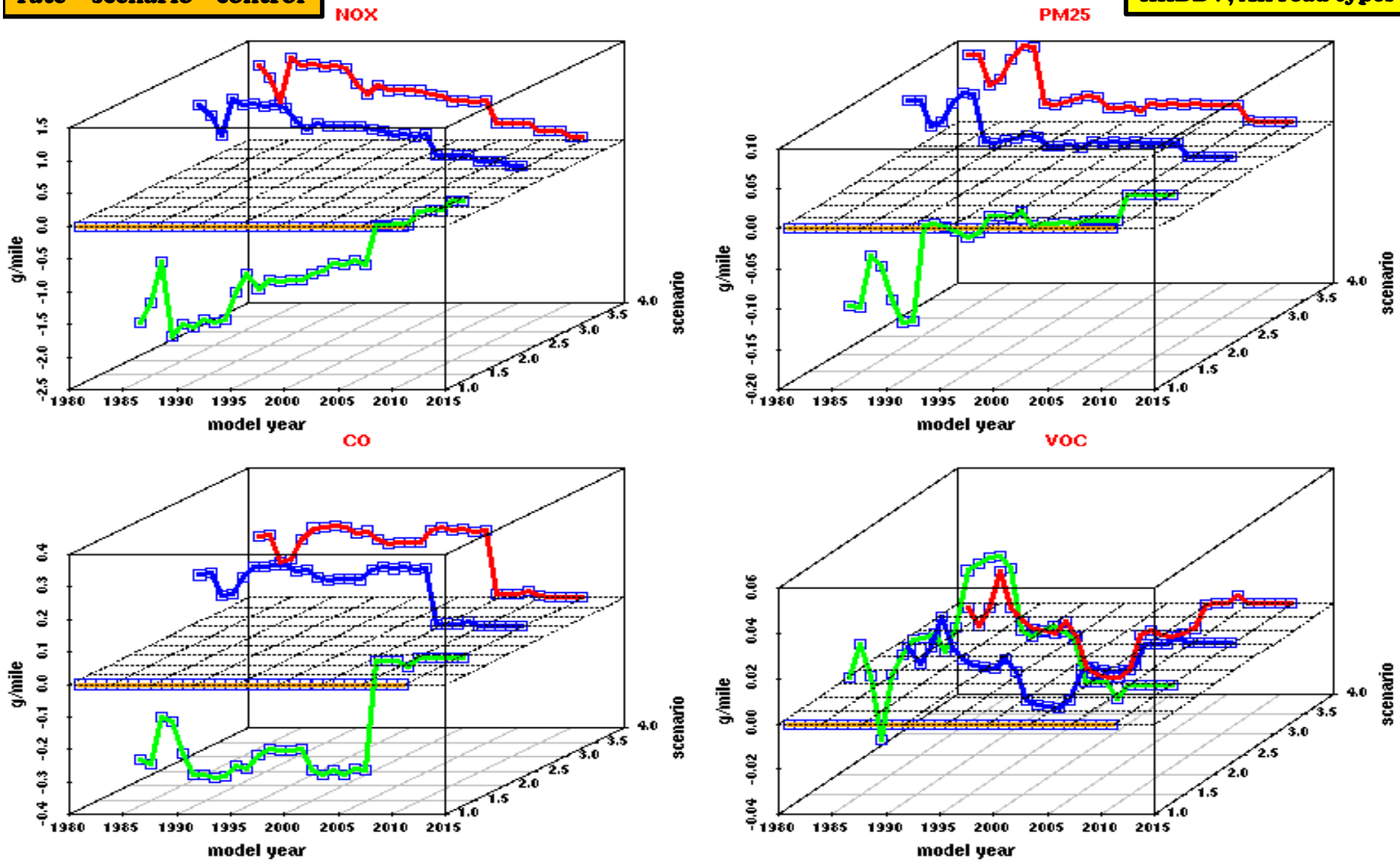
-- The entire HDGV fleet for scenario1 has lower rates than control case. Scenario2 and 3 both have higher rates than control case.

# Effect of Fleet Age on EXR – Fairfax 2011

**rate = scenario -- control**

Differences in EXR Emission Rate for 2230074 at T=70F, RH=60%

**HHDDV, All road types**




-- Rates are shown as differences between scenario and control case. Control case subtracts itself to be zero for all model years.

-- Similarly, the entire HHDDV fleet for scenario1 has lower rates than control case. Scenario2 and 3 both have higher rates than control case.

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  Start versus running emissions
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# Process Separation Algorithm

## Start Emissions versus Running Emissions – lookup table mode

**Based on additive mechanism and mass balance:**

**Example: NOx**

**RPD = Running Emissions = EXR + CXR**

**RPV = Start + Extended Idle Emissions = (EXS + CXS) + (EXT + CEI)**

**Start : Running = (RPV – (EXT + CEI)) : RPD** <-- exact approach

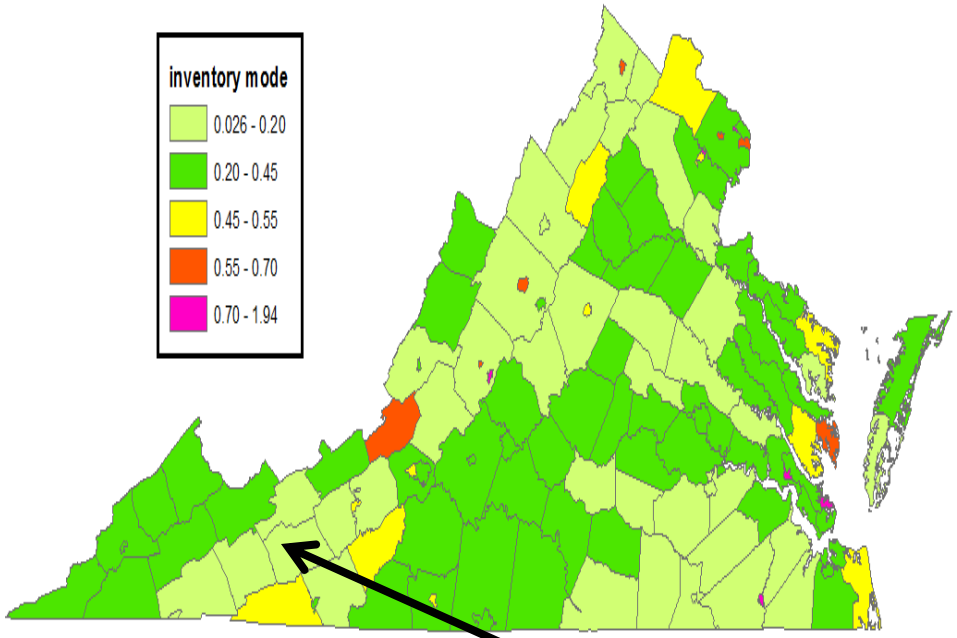
**Start : Running =~ RPV : RPD (if extended idling is small)** <-- approximation

**can be analyzed by county, by SCC7 (vehicle type), by pollutants, or by day**

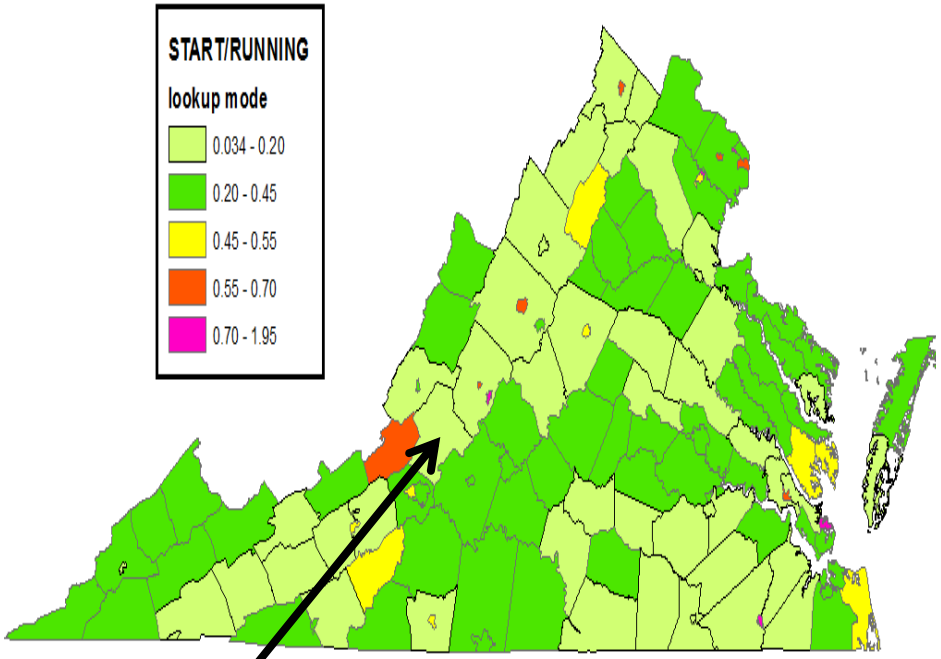
*** VOCs separation is a little complicated, because it involves a lot more processes;**
*** For Inventory mode, start and running can be estimated directly if process is requested in the runspec.**

# Ratio of Start to Running Emissions -- NOx

**Inventory mode**




**Lookup table mode**




**Interstate I-81 (very high VMT)**

-- Estimates of start and running emissions by inventory mode and lookup table mode are similar.
-- NOx ratios are below 50% throughout the commonwealth, indicating running is the larger contributor.
-- Counties with ratios higher than 50% are small in size with very low emissions.

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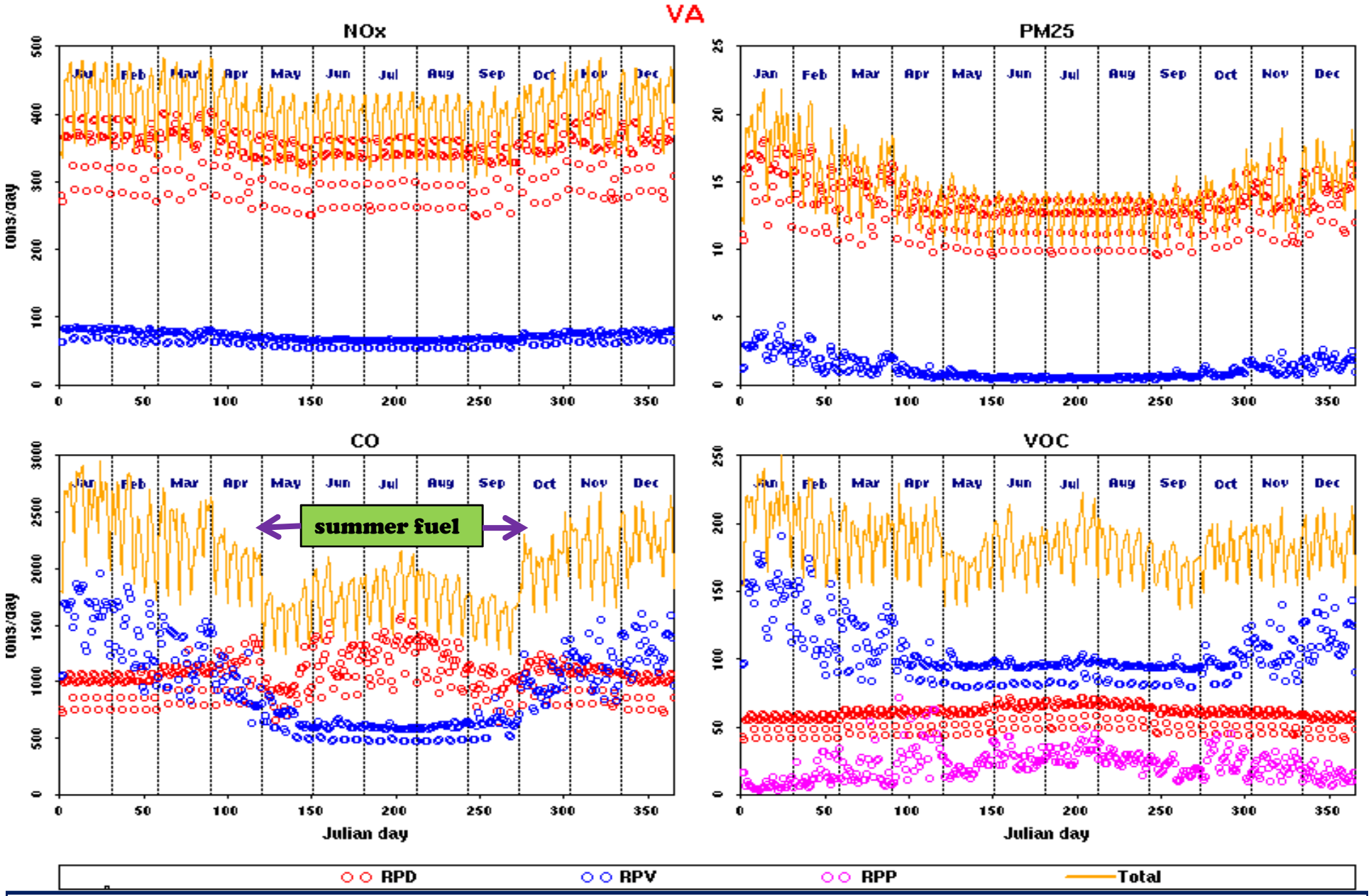
  - Improving hourly emissions
- Summary and Conclusion

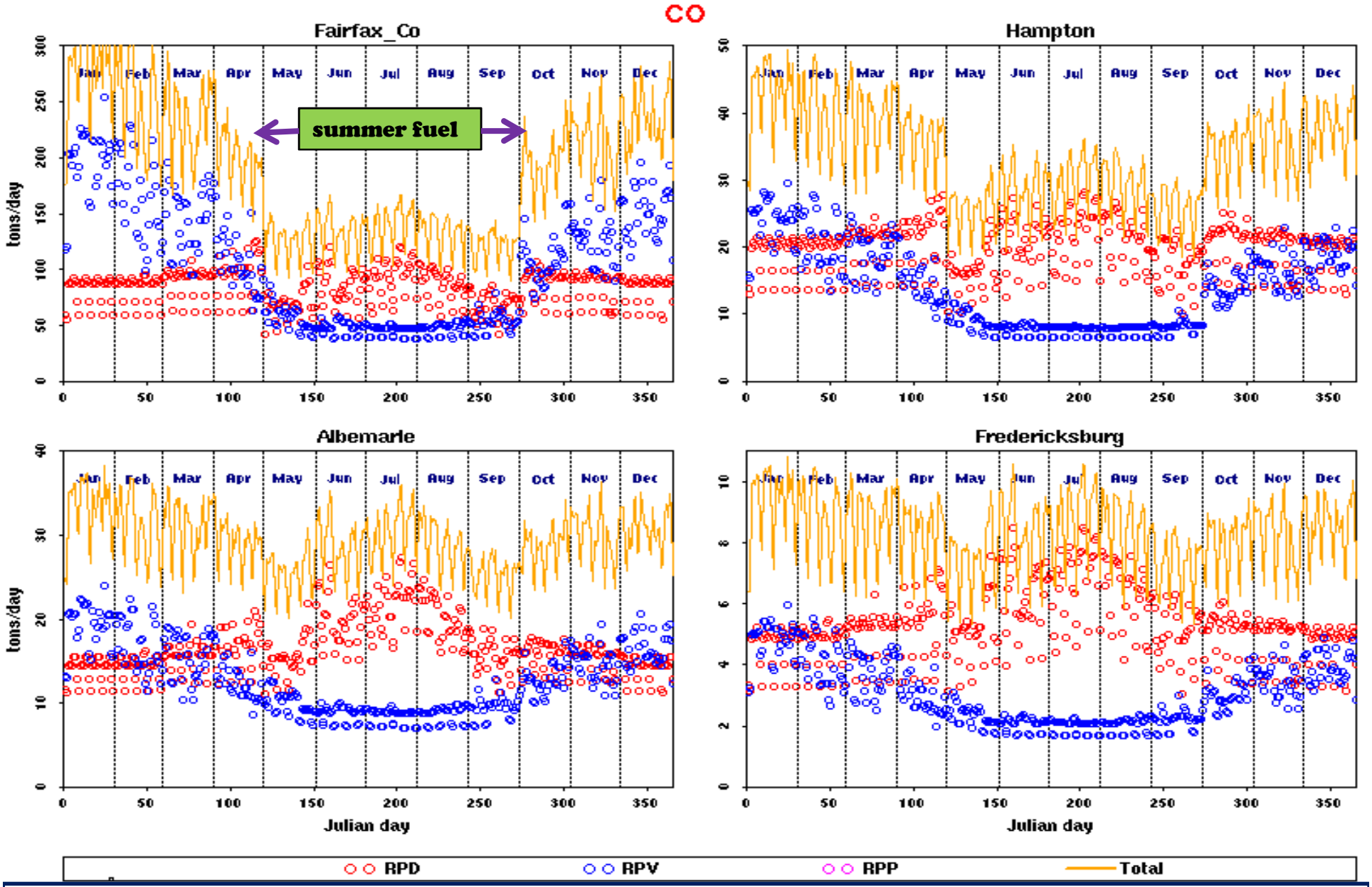
# VA 2011 Daily Temporal Profiles for Vehicular Emissions




-- For NOx and PM2.5, RPD dominates among the three sectors, accounting for >80% of the two pollutants.

-- By contrast, for CO and VOCs, RPV is the dominating sector, whereas RPP is the least contributor to VOCs among the three.

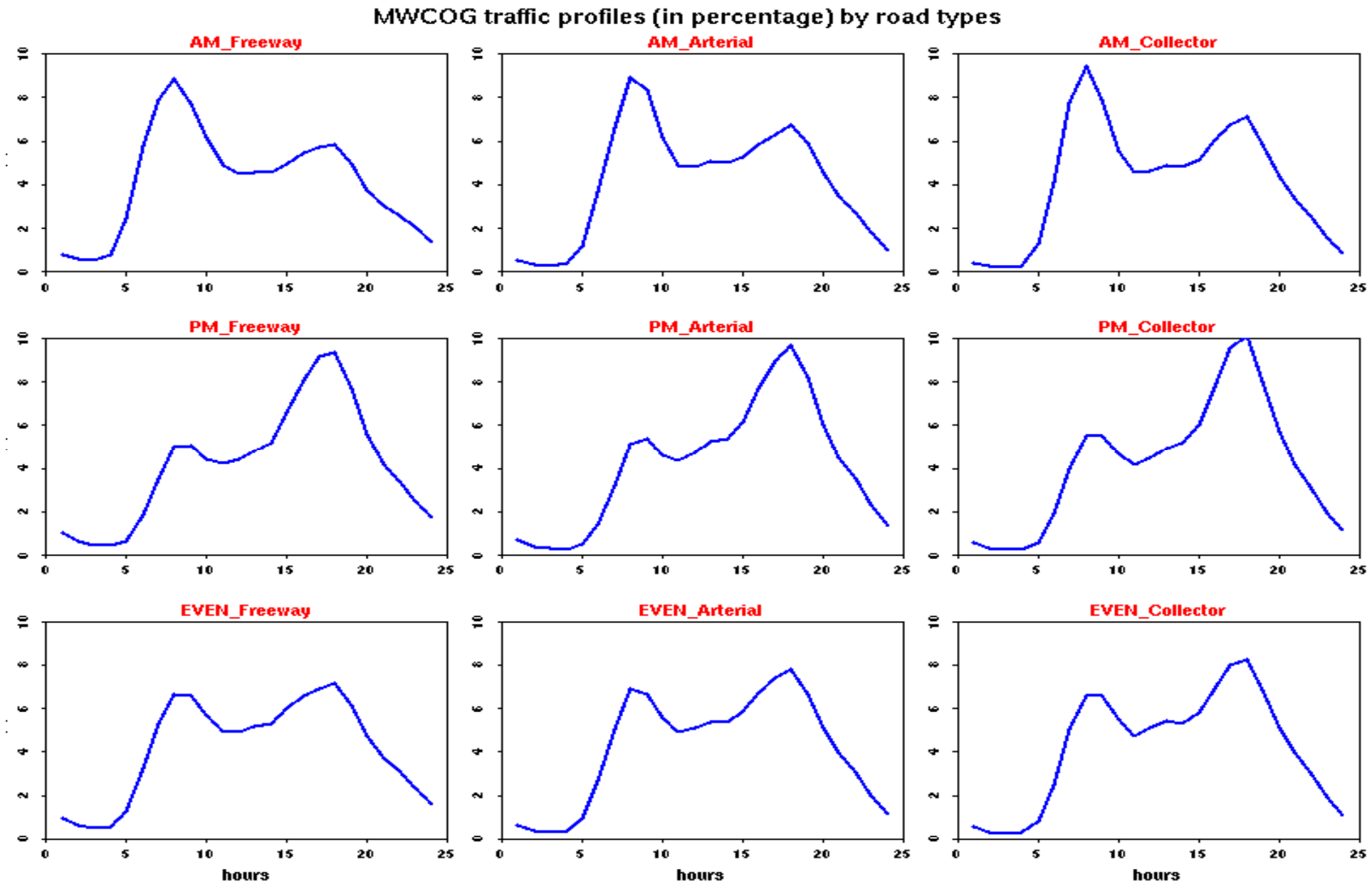
# VA 2011 Daily Temporal Profiles for Vehicular CO Emissions




-- Daily profiles by county show some variations. RPP sector (VOCs only) does not contribute to CO.

-- Discontinuity due to two fuel months starts to diminish as county emissions get smaller (Fairfax -> Hampton -> Albemarle -> Fredericksburg).

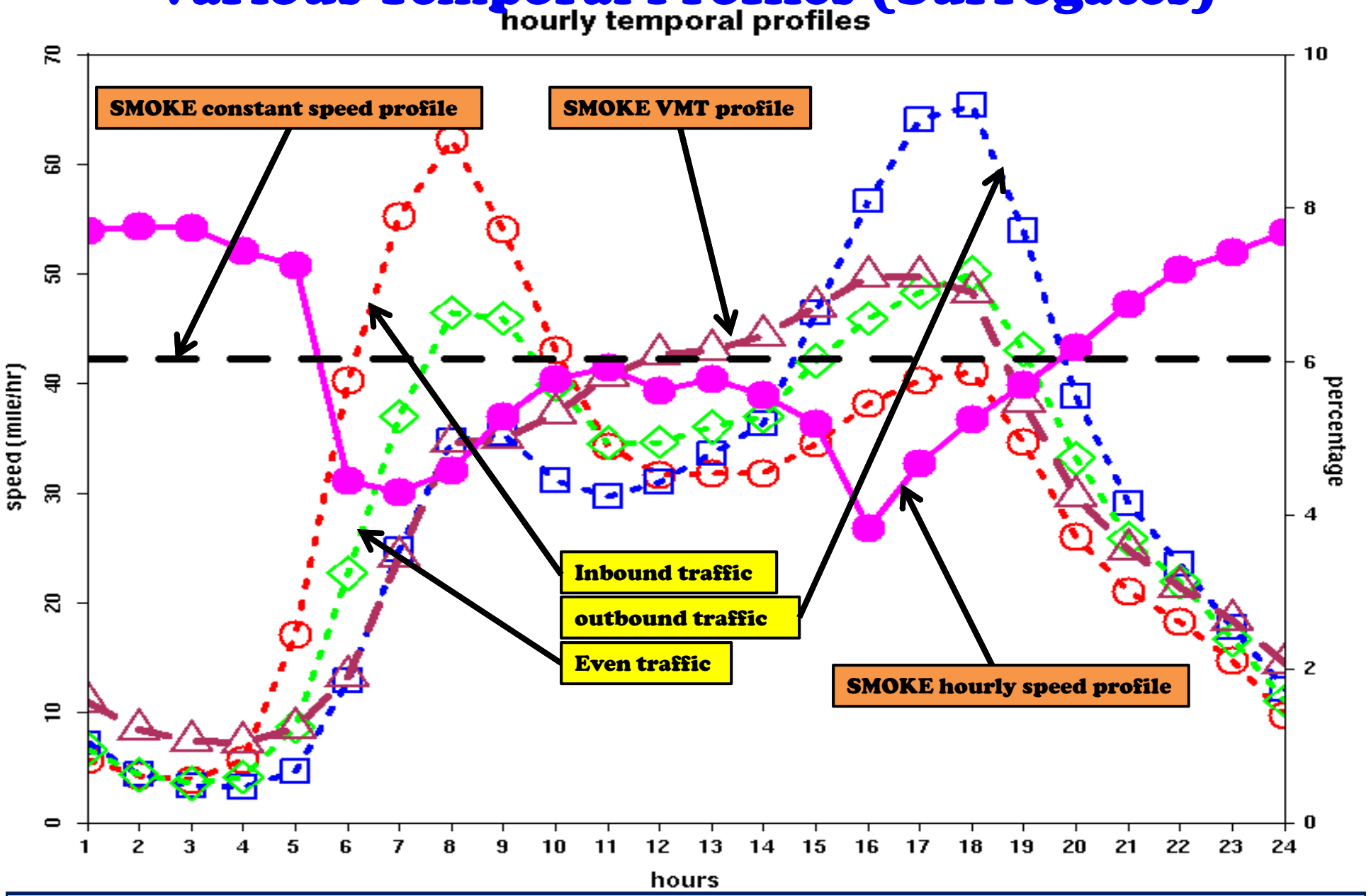
# Temporal Traffic Patterns by Road Types




-- AM: inbound traffic to the city; PM: outbound traffic from the city; EVEN: inbound and outbound evenly distributed.

-- Percentage is based on traffic counts observed at a particular location.

# Various Temporal Profiles (Surrogates)




-- Neither SMOKE VMT profile nor hourly/constant speed profile is a good representation to actual traffic patterns.

-- VMT and speed profiles are inconsistent: vehicles moving at lower speed in evening rush hours end up traveling more miles.

# Summary and Conclusion

- Three dimensional graphics is an effective way in understanding complex processes and parameters in MOVES.
- Emission processes are additive in MOVES and SMOKE-MOVES.
- Lookup tables generated from SMOKE-MOVES can be treated as a series of systematic sensitivity runs. They contain general and useful information.
- Relative humidity has greatest impact on emissions when temperature is above 60F.
- Higher Reid Vapor Pressure generates higher emissions. The common practice of two fuel months may be inadequate.
- Slight variation of fleet age distribution has significant impact on emissions.
- Additive mechanism and mass balance allow separation of MOVES emission process. Running emissions are much larger than start emissions.
- Hourly vehicular emissions can be improved by suitable temporal surrogates.